HYCOM Coastal Ocean Hindcasts and Predictions: Impact of Nesting in HYCOM GODAE Assimilative Hindcasts

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LONG-TERM GOALS

The overarching goal is to determine how simulations and forecasts of currents and water properties in the coastal ocean, and the scientific understanding obtained from them, are influenced by the initial and boundary conditions provided to nested coastal ocean models. In addition to surface

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atmospheric forcing and coastal freshwater runoff, the coastal ocean is influenced by offshore ocean variability resulting from processes ranging from basin-scale wind-driven gyre and thermohaline circulation down to regional and local circulation associated with boundary currents and eddies. To accurately represent the offshore ocean influence, the coastal model must be nested within fields that accurately represent (1) the initial state of the ocean throughout the model domain and (2) currents and water properties at the nested model boundaries during the model run. We specifically evaluate the HYCOM (HYbrid Coordinate Ocean Model) data assimilation products developed as part of the Global Ocean Data Assimilation Experiment (GODAE) for providing these fields. Coastal model evaluation is being performed over a range of environments to provide feedback that will guide improvements to the HYCOM-GODAE products. The overall regional focus encompasses the coastal northern and eastern Gulf of Mexico through the Florida Straits, which represent a broad range of shelf geometries, river runoff, seasonal atmospheric forcing, and offshore forcing. Three regions are emphasized: (1) the West Florida Shelf (WFS); (2) the South Florida Coastal Region (SoFLA), including the Florida Straits, the Florida Keys and Atlantic Keys shelf, Florida Bay, and the adjacent southwest Florida shelf; and (3) the coastal northern Gulf of Mexico (NGoM). This project focuses only on downscaling open-ocean variability to the coastal ocean (one way nesting).

OBJECTIVES

Specific operational objectives include:

1. determining how changes in the initial and boundary conditions provided by HYCOM-GODAE products (e.g. resolution, free-running versus assimilative, assimilation methodology) influence the capability of nested models to hindcast and predict the coastal ocean environment;
2. evaluating the coastal hindcasts and predictions against observations that include existing elements of the Coastal Ocean Observing System (e.g. SEACOOS, GCOOS);
3. identifying the most useful observations for evaluating and improving coastal ocean models that should be maintained as part of a coastal observation network;
4. evaluating HYCOM development as a coastal ocean model against observations and against simulations by other model types (ROMS and POM); and
5. providing feedback that will improve the HYCOM GODAE products that provide initial and boundary information to nested coastal (and regional) models.

Specific scientific objectives in the three coastal domains include:

6. determining the impact of offshore currents (Loop Current and eddies, Florida Current; basin-scale wind-driven gyre circulation) on coastal ocean circulation (all three domains);
7. determining the impact of higher-frequency offshore variability (rectification), if any, on the annual cycle of coastal circulation (all domains);
8. studying the impact of vertical mixing and friction (including the surface and bottom boundary layers) on coastal circulation, taking advantage of the multiple vertical mixing choices (Halliwell, 2004) in HYCOM (all domains);
9. quantifying and understanding shelf-slope exchange processes (all domains);
10. studying the dynamics of transient eddies, including the Tortugas eddy, in the Florida Straits (SoFLA domain);
11. studying circulation and nutrient transport in South Florida coastal seas, emphasizing ecologically important areas of Florida Bay and the Florida Keys influenced by Everglades runoff in support of the Comprehensive Everglades Restoration Project (SoFLA domain);
12. understanding impact of the Mississippi river plume (locally in the NGoM, remotely in the WFS and SoFLA domains); and

13. studying the coastal ocean response to hurricanes (all domains).

APPROACH

Free-running nested coastal ocean simulations are being conducted in all three regions. Sensitivity to initial and boundary conditions are being assessed by nesting free-running coastal ocean models within different outer model products provided by the evolving HYCOM nowcast-forecast system, then comparing simulated fields to each other, to the outer model fields, and to in-situ observations. Evaluation of coastal hindcasts is now underway, and evaluation of forecast runs is planned during the upcoming year, taking advantage of existing ocean observing systems. For the SoFLA domain, this includes coastal radar (WERA) and an extensive observational network centered in Florida Bay supported by NOAA for the Everglades Restoration Project. For the WFS domain, this includes the extensive observational network maintained by the University of South Florida by R. Weisberg and colleagues. For NGoM, this includes observations acquired by NRL and other regional research institutions. The most optimal runs identified by the evaluation effort are being used to address the scientific objectives listed above. The initial evaluation and scientific analysis has focused on years 2004 and 2005.

WORK COMPLETED

Three HYCOM-based outer model analysis products that use data assimilation to improve realism are now available for evaluation: ATL-OI, the original Atlantic Ocean optimum interpolation system where sea surface height anomalies measured by satellite altimetry are assimilated; GoM-NCODA, the initial test of the new NCODA assimilation system (Cummings, 2005) conducted within the GoM and nested within fields derived from HYCOM climatological Atlantic simulations; and GLB-NCODA, the initial global NCODA run. To assess how the improved realism of offshore ocean forcing provided by these products influences our coastal simulations, the models have also been nested in a free-running ocean simulation where the locations of offshore eddies and boundary currents were unconstrained by data assimilation.

For the West Florida Shelf domain, a set of experiments has been completed at RSMAS to document sensitivity of nested free-running HYCOM simulations to initial and boundary conditions provided by the three data-assimilative HYCOM products, and also provided by a free-running model. At the University of South Florida, a regional ROMS model of the West Florida Shelf has also been nested in the HYCOM outer models. Results and visualizations from this ROMS modeling effort are updated daily and are available at http://ocgmod1.marine.usf.edu/WFS, and also at http://ocgweb.marine.usf.edu. The set of experiments in the regional SoFLA domain have been nested in two of the three HYCOM data-assimilative products (ATL-OI and GoM NCODA) along with the free-running GoM simulation. The experiments have also focused on different atmospheric forcing datasets, different river plume parameterizations (line source, point sources, variable total discharge), and different vertical resolution. A new high resolution (~900 m) nest (FKEYS, 83.4 to 79.0°W, 22.8°N to 26.1°N) has been set-up within the SoFLA domain with the important Shark river runoff from USGS prescribed as a line source of fresh water input along the Ten Thousand Island coastline. A simulation for 2004-2005 has been completed and analysis of results is under way, including comparison of model fields to WERA high-frequency surface current measurements (http://iwave.rsmas.miami.edu/wera). The model realistically reproduces the small eddies that propagate along the Florida Keys and southeast Florida coast and have an important impact on coastal marine life. Results from the West Florida Shelf and SoFLA domain were presented at an international workshop on the impact of open ocean boundary conditions on nested simulations of the coastal ocean held in Liverpool, UK. Papers from this workshop are being published in a special issue of the journal

Ocean Dynamics. The PI (G. Halliwell) was one of the guest editors for this volume. Two of the papers (Halliwell *et al.*, 2008; Kourafalou *et al.*, 2008) were derived from this project.

The realistic NGoM domain covers the coastal northern Gulf of Mexico (82.8^{0}W to 95^{0}W and 28^{0}N to 30.5^{0}N) at a resolution of ~1.8 km. A constant Mississippi river discharge of 13,000 m^3/s is applied and equally distributed over 3 passes (Southwest Pass, South Pass, Pass a Loutre). A suite of experiments have been conducted documenting the influence of the atmosphere along with offshore eddies on the transport of relatively fresh Mississippi River water.

RESULTS

In all three domains, the choice of outer model has little influence on simulated velocity fluctuations over the inner and middle shelf where fluctuations are dominated by the deterministic wind-driven response. For the West Florida Shelf, improvement is documented in the representation of alongshore flow variability over the outer shelf, driven in part by the intrusion of the Loop Current and associated cyclones at the shelf edge near the Dry Tortugas. This improvement was realized in the simulation nested in the global ocean hindcast, the only outer model choice that contained a realistic representation of Loop Current transport associated with basin-scale wind-driven gyre circulation and the Atlantic Meridional Overturning Circulation. Improved representation of outer shelf currents is important for modeling water exchanges between the shelf and open-ocean, which has important implications for marine life. Concerning temperature on the West Florida Shelf, the non-assimilative outer model had a cold bias in the upper ocean that was substantially corrected in the data-assimilative outer models, leading to improved temperature representation in the simulations nested in the assimilative outer models. In the SoFLA domain, the outer model choice did have a significant positive impact on correctly reproducing the path of the Florida Current and associated eddies through the Straits of Florida. Since the eddies associated with Florida Current path fluctuations travel from southwest to northeast through the Straits of Florida, these features can only enter the domain of the nested model if it is correctly provided by the outer model. This is not possible when the SoFLA model is nested within climatology or a free-running model, neither of which are capable of correctly representing the location of ocean eddies and the Florida Current path. This success is important because the eddies passing through the Florida Straits to the north of the Florida Current strongly influence the recruitment and abundance of important species such as the Florida Lobster (Sponaugle *et al.*, 2005).

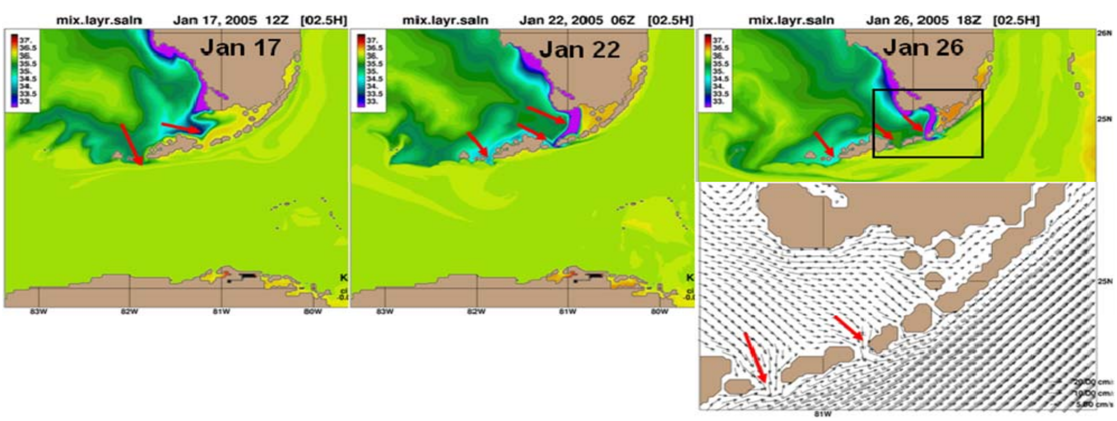

Figure 1. Simulated salinity distribution in the FKEYS model mixed layer on Jan 17, 22 and 26, 2005. Red arrows show the low salinity intrusion to the Florida Bay and the Atlantic side of the Florida Keys through passages between islands. Current vectors are shown for the zoomed area.

To study flow and salinity variability in Florida Bay and the Florida Keys, a very high resolution (about 1 km) model is nested within the SoFLA domain. Changes in salinity associated with planned activities under the Comprehensive Everglades Restoration Project have potentially significant effects on habitat changes. Fresh runoff from rivers outside the FKEYS domain is passed into the domain from the outer model. An interesting result is that freshwater inputs from rivers on the Southwest Florida shelf may alleviate hypersalinity conditions in Florida Bay (and hence the Atlantic Florida Keys shelf) during the dry season (winter to spring), when precipitation is at its lowest; see the salinity fields in January, 2005 (Fig. 1) for the evolution of a freshening event just north of the keys. The gradual lowering of salinity is supported by the velocity field, and it was validated against in situ observations in west Florida Bay (Tom Lee, unpublished data).

The NGoM domain is being used to study the fate of the fresh Mississippi River plume which can have a significant impact on coastal marine ecosystems. Wind variability tends to drive this fresh water to the east or west along the coast depending on direction. However, offshore eddies can force cross-shelf flow along the outer shelf that can draw fresh water plumes into the open ocean (Figure 2). The location of the offshore eddies is provided by the outer model within which the coastal model is nested, again indicating the critical importance of GODAE ocean products to provide this information to the nested model.

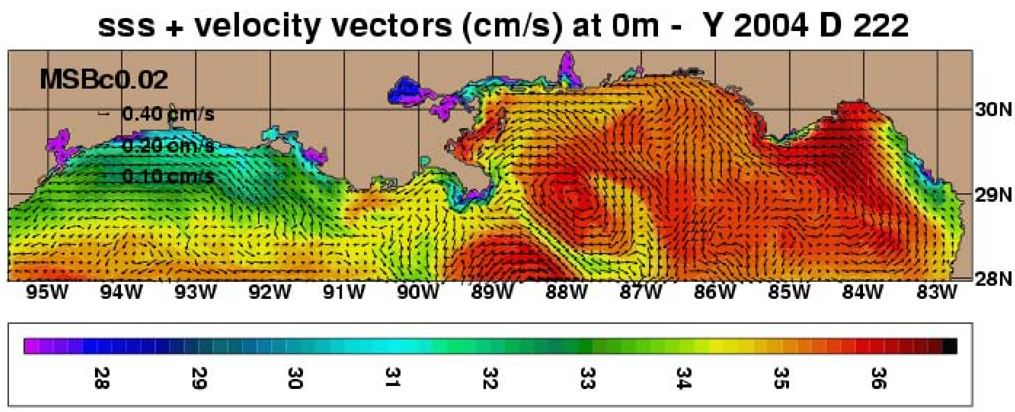

Figure 2: Snapshot of sea surface salinity and surface velocity vectors from a realistic simulation of the NGoM-HYCOM domain, on August 09 2004. The circulation induced by the tip of a Loop Current Eddy and an associated cold core eddy generates offshore flows that effectively remove coastal waters from the Mississippi Delta to the offshore region, which can be seen by the coherent filament east of the Delta.

IMPACT/APPLICATIONS

National Security

The ocean model used in this study (HYCOM) will become the operational ocean model used by the U. S. Navy by FY2008. The work performed under this project will lead to model improvements that will positively impact Navy operations.

Economic Development

Improvement in our capability to model physical variability of the coastal ocean will impact commercial marine operations, such as the impact of ocean currents on marine transportation and on oil rigs.

Quality of Life

Improved capabilities in modeling physical variability in the coastal ocean will be very important for studying the response of coastal ecosystems and fisheries to changes in the ocean, and also for studying pollution dispersal and conducting search and rescue operations. Results of this study demonstrate the impact of coastal ocean models for monitoring and forecasting the coastal ocean, and demonstrate the necessity of using high-quality ocean products produced by the Global Ocean Data Assimilation Experiment to provide information on ocean variability occurring outside the coastal domain of interest.

RELATED PROJECTS

The SoFLA study is also part of the environmental monitoring effort being conducted as part of the Comprehensive Everglades Restoration Project (CERP). The nested SoFLA model is providing the offshore boundary conditions for the Florida Bay modeling team within CERP. At the University of South Florida, a complementary project was initiated for the Cariaco Basin off of Venezuela where a high resolution ROMS model was nested in HYCOM. This project will also be used to evaluate the initial/boundary conditions provided by the HYCOM-GODAE products. V. Kourafalou (PI) leads the Hydrodynamic Modeling project of an integrated, multi-task UM/RSMAS and TAMU effort for integrated ecosystem management and prediction in the Caribbean Sea and Gulf of Mexico. In collaboration with G. Halliwell (co-PI), the Wider Caribbean Region model has been set up and nested within the global HYCOM. V. Kourafalou (PI) and G. Halliwell (co-PI) have a NOAA funded project that is connected to the Northern Gulf of Mexico Cooperative Institute. They will use the NGoM-HYCOM domain to develop a framework for Observing System Simulation Experiments (OSSE's, Atlas 1985) that will be utilized to design optimal observing systems in the NGoM domain. Through an NSF ancillary project (V. Kourafalou, co-PI with S. Sponaugle), the FKEYS-HYCOM is being coupled with the ecological population connectivity BOLTS model (Biophysical Larval Transport System). The coupled model will be used for the study of small eddy variability in the Florida Current and for biophysical simulations of larval transport.

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